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Fifth Graders as App Designers: How Diverse Learners Conceptualize Educational Apps

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Abstract

Instructional designers are increasingly considering how to include students as participants in the design of instructional technologies. This study provides a lens into participatory design with students by examining how students conceptualized learning applications in science, technology, engineering, and mathematics (STEM) by designing paper prototypes of a learning application related to circuits and electricity. Eighty-nine fifth grade students, including students with learning disabilities and English language learners, participated in this study. Findings of this study indicated that all students conceptualized learning applications as a game and built scaffolds into the gameplay to encourage both content mastery and advancement in the game. Each of the paper prototypes that the students developed provided opportunities for progressive complexity of gameplay related to electricity and circuits as well as options for customization and building background knowledge. Finally, this article identifies implications of these results and considerations for future research. (Keywords: participatory design, mobile learning, STEM, app design)

Schools face increasing expectations to provide academically diverse students with science, technology, engineering, and mathematics (STEM) instruction that results in improved performance. Despite many efforts, students in the United States continually underperform compared to their peers in other industrialized countries (Aud et al., 2012). When looking at STEM performance domestically, this underperformance is intensified for students with disabilities, English language learners, and others at risk for academic failure (Leddy, 2010).

To improve struggling learners' STEM performance, educators and researchers have emphasized the importance of authentic STEM learning that

results in deeper understanding of science and mathematics. Despite this emphasis, many students continue to struggle and dislike STEM learning activities (Marino, Tsuruski, & Basham, 2011). Students find STEM learning difficult for many reasons, including an overreliance on inaccessible textbooks, lack of disciplinary background knowledge, and abstract problem-solving procedures (Israel, Maynard, & Williamson, 2013; Marino, 2010).

Increasingly, researchers look to instructional technologies to support students' engagement and content acquisition in STEM areas (Mayo, 2009). Emerging research suggests that instructional technologies such as video games (Marino & Hayes, 2012) and computer simulations (AAAS, 2004; FAS, 2006; National Research Council, 2011) can support STEM instruction in a way that is flexible, pedagogically sound, and motivating to students. Gaming technologies can engage students in STEM at the convergence of education, entertainment, and social commitment (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). By gamifying learning, these technologies provide intrinsic rewards to the user (Charles, et al., 2005) and offer personalized educational experiences (Clark, Nelson, Sengupta, & D'Angelo, 2009).

Despite the promise of gaming technologies for engaging students in STEM learning, traditional math and science instruction rarely makes use of such technologies (Marino & Beecher, 2010). This is in sharp contrast to the fact that most students, including students that typically underperform in STEM, indicate that they engage with commercial gaming technologies (National Research Council, 2011).

The well-documented inconsistency between K–12 students' instructional and commercial technology usage should be further explored to ascertain what aspects of gaming could support student learning. One approach is to understand how students conceptualize technology to support their own learning. This study made use of a participatory design process to investigate how fifth grade students with diverse learning needs conceptualized the use of mobile technologies in their own learning. Three research questions guided this study:

1. How do students conceptualize a mobile device application (app) that is designed to teach STEM content related to electricity and circuits?
2. In designing paper prototypes of mobile learning applications, what design features do students include?
3. At what level do students include video game design elements (e.g., game mechanics) in their mobile application prototypes?

Students as Participants in the Design Process

To effectively consider how diverse learners use mobile applications to meaningfully access and engage in STEM learning, it is important to gain their perspectives as part of the technology design process. In traditional curriculum development, however, student input is often nonexistent or

does not enter into the conversation until the curriculum has already been approved. Even in technology development, although students may provide some level of feedback as part of usability testing, they typically do not participate in the initial design process (Nesset & Large, 2004).

Some technology developers, however, have started involving students in the development of technology-supported learning products through a user-centered design framework. User-centered design cycles often involve the end users in evaluating and providing feedback to the designers once a prototype has been developed (Nesset & Large, 2004; Nousianinen, 2009). Despite the fact that these users are engaged as testers, and a great deal of revision can still occur based on their input, the participants' role remains largely passive, as they react to technologies rather than participate in the development of those technologies (Guha, Druin, & Fails, 2011).

To further involve young learners in developing technologies designed for them, few designers have accepted a participatory design philosophy, which is an emerging philosophy that is based on empowerment, choice, and inclusion (Nousianinen, 2009). Participatory design necessitates that designers include these participants, including children, at every stage of the design process. In this manner, the children become designers alongside the professional software developers (Nesset & Large, 2004). They become co-researchers and definers of what is relevant and appropriate for them (Guha, Druin, & Fails, 2011).

According to Gee (2003), good games incorporate aspects of learning that include production, customization, and agency. Children can determine if a game is good, but, when asked, they struggle in clearly articulating the details of what makes a good game (Peppler & Kafai, 2007). Technology designers who want to involve children in the design process must think differently about how to elicit input from children in an authentic and meaningful way, because simply asking students for their thoughts about game design will likely not reveal meaningful content that informs the technology design process. Although this approach has challenges (Nesset & Large, 2004), the participatory design process has the potential to result in a better product that is relevant and useful to the intended product users.

A constructionist view of participatory design acknowledges the instructional pedagogy involved in students constructing their own instructional technologies and grappling with both the design decisions and the content of the games (Kafai, 2006). Within this framework, there is a general acceptance that students do not design technologies in a vacuum. Rather, they participate in the design of instructional technologies by applying their knowledge and understanding of three broad areas: (a) knowledge of and experience with commercial and instructional games and technologies, (b) understanding of the instructional content addressed by the technology, and (c) their own general and technology-specific learning preferences. Each of these areas informs the design decisions that they make (see Figure 1, p. 56). Numerous studies

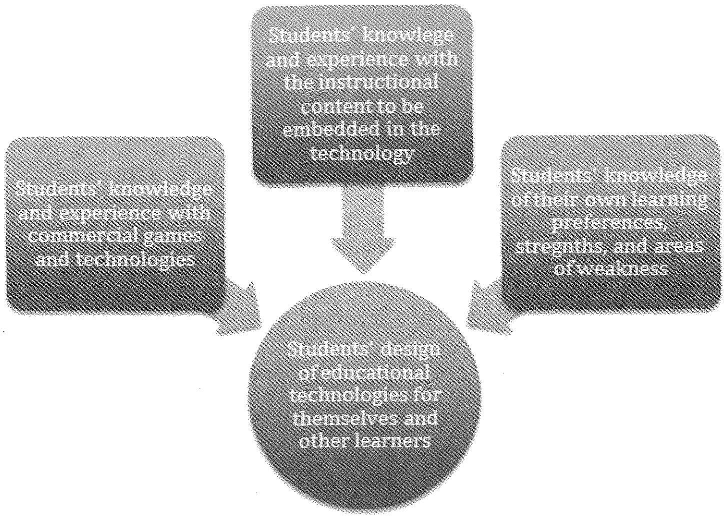


Figure 1. Students as instructional designers.

and news articles cite that the majority of students have experience with commercial and educational technologies and games that informs their expectations for instructional technologies used for learning, and therefore informs their own design decisions. In addition to this technology experience, to fully participate in the design of educational technologies, the students must have a fairly sophisticated understanding of the content addressed by the technology. Without this understanding, they may design technologies that perpetuate misconceptions or provide only a superficial experience with the technology. Lastly, students bring their own learning preferences into their design processes. These preferences may include ways of accessing and interacting with instructional content within the game.

Methods

Setting and Participants

This study took place in a large Midwestern suburban elementary school. The school's science teachers participated in professional development to support their integration of engineering design principles into science instruction and used a curriculum developed by the Boston Museum of Science called Engineering is Elementary (EiE), which promotes scientific literacy through hands-on design activities that incorporate real-world challenges related to science, engineering, and technology content (Boston Museum of Science, 2011).

The student demographics in this school included 79% white (non-Hispanic), 5% Hispanic, 8% African American, 6% Asian/Pacific Islander, and 2% other. Approximately 12% of the students were considered

economically disadvantaged. Within this school, we chose one science teacher with four sections of fifth grade science to participate in this study due to the high level of linguistic and disability-related diversity in her classes. In the four science classes, 89 students obtained signed parental consent and thus participated in the study. These students included 41 females and 48 males with an average age of 11 years of age. The students represented a broad range of students found in inclusive public school classrooms, including students with disabilities (*N* = 6), English language learners (*N* = 5), English language learners with disabilities (*N* = 3), teacher-identified struggling learners (*N* = 12), students receiving gifted education services (*N* = 17), and students not receiving additional services (*N* = 46). For the category of "teacher -identified struggling learner," the teacher identified students who were not formally identified as having a disability and qualifying for special education services, but who exhibited difficulties in learning science content and required extra instructional support through the school's Response to Intervention (RtI) system.

Instructional Content

Prior to data collection, the students participated in an EiE unit called An Alarming Idea: Designing Alarm Circuits: Electricity and Electrical Engineering for Elementary Students. In this unit, the students learned the relationship between electricity and electrical engineering, including the origins of electricity and the makeup of different types of electrical circuits (Boston Museum of Science, 2011).

Data Collection

We collected data during the participants' science classes. Each class was 50 minutes in length. All engineering instruction and subsequent data collection occurred during the students' science classes. Once the students completed the EiE unit, we asked the students for their input in designing a mobile device app that would help students learn about electricity and circuits. It is important to note that we did not give the students any previous introduction, background, or examples of apps or games related to electricity or circuits. We instructed the students to collaboratively design paper prototypes of their app. These instructions included guiding questions to drive their creative process; however, we did not give the students specific directions about the appearance, features, or functions of their app designs. Lastly, we assigned the students group roles that included illustrators (i.e., students drawing the paper prototypes), systems analysts (i.e., students providing written explanation of the apps), and recorders (i.e., students capturing video during the design process). To minimize the possibility of student groups gaining insight from each other, we grouped the students' tables in such a way that there was separation between the groups. Additionally, three of the researchers and

the classroom teacher stayed in close proximity to the groups to note if any groups collaborated with each other. When comparing field notes after each class, we noted that each group worked independently and were not influenced by the other groups. We took no measures to ensure that students did not discuss their app designs after class with members from other classes; however, as the intervention started and ended on the same day in each of the classes, their initial designs and conceptualization occurred prior to any knowledge of this activity, so it can be assumed that the designs were original to each group (see the "Limitations" section of this article, p. 76, for further discussion of this issue).

The researchers and teacher collaboratively grouped the students into 15 heterogeneous groups of four to five students. We provided the students paper templates with blank mobile device borders on which the "illustrators" drew the paper prototype of their app. The students could obtain additional templates as needed. We also provided them with lined paper, on which the "systems analysts" wrote a summary of the app screens, indicated how the app would function, and described features contained within the app. Finally, we gave the "recorders" digital cameras to capture video of the app design process and tasked them with chronicling the design process. The recorders also reported the rationale behind the appearance and function of the group's app features.

During the design process, the research team circulated among the students to collect observational data and offer additional template sheets upon request. We did not interject opinions or ideas into the students' design processes and purposefully refrained from influencing the students' design.

Data Analysis

We first qualitatively analyzed the paper prototype app designs and accompanying written descriptions to identify design themes (Hatch, 2002). We reviewed each app design to identify salient design components and then discussed emerging general themes and subthemes. After initial theme agreement, we completed the coding process. Throughout this process, we met regularly to discuss the resulting themes and subthemes and made adjustments as needed.

Video captured during the design process served as a tertiary data source that we analyzed once coding of the paper protocols and written descriptions was complete. Because the recorders captured group conversations during the design process, these videos served as a record of the students' collaboration as they conceptualized their electricity and circuits app. We selective transcribed these video recordings and coded them to triangulate with themes that emerged from the paper prototype app designs and the written descriptions of the apps.

Once we completed qualitative coding, we quantified these data for descriptive data analysis. Creswell, Fetters, and Ivankova (2004) explained that this process generally involves transforming qualitative data into quantitative data

Table 1. Themes and Subthemes

Theme	Subtheme	Example
Homepage	Graphically intuitive presentation	Illustration of a flashing light bulb in the title of the app
	Content offered through game play with embedded player choices	Illustration of a challenge game
	Clear navigation	Navigation boxes to click
General Design	Apps as games	Increased content complexity as students' progress
	Multiple settings for choice	Options for language and background music
	Embedded vocabulary supports	Visual dictionary options
	Scaffolded progression in complexity	Leveled game play
	Immediate feedback	Intelligent agent provides error messages and corrective suggestions
	Explicit navigation	Boxes with terms such as click here
	Built-in support for gaining foundational knowledge	Content-specific videos and external links

by counting the codes and themes within the qualitative data to ascertain the frequency of each theme and subtheme within the entire data set. Thus, for each subtheme, we determined the frequency of occurrences within the 15 groups of students to determine which design features were most prevalent within the students' app paper prototypes.

Findings

This study resulted in two broad theme areas: distinct homepage design features and general design features. Within each of these two themes, several subthemes emerged. Table 1 provides the themes, subthemes, and examples.

Theme Definitions

The first broad theme related to the types of structures was provided on the homepage of the paper protocols. Homepages generally were defined as the app landing pages, from which the students conceptualized further navigation and activities. The second area involved general design of the app, which specified the interactions and engagement the students conceptualized for their app.

Paper Prototype Homepages

The students conceptualized homepages as explicit landing pages from which all activities and content manipulation would begin. Within the homehpage data, three subthemes emerged: (a) graphically intuitive presentation, (b) gameplay and choice, and (c) clear navigation.

Graphically intuitive presentation. When designing the homepages, the students focused on presenting information in an intuitive manner. For example, 13 of the 15 groups presented visually intuitive graphics, such as flashing electric currents to indicate the electricity content or a picture of

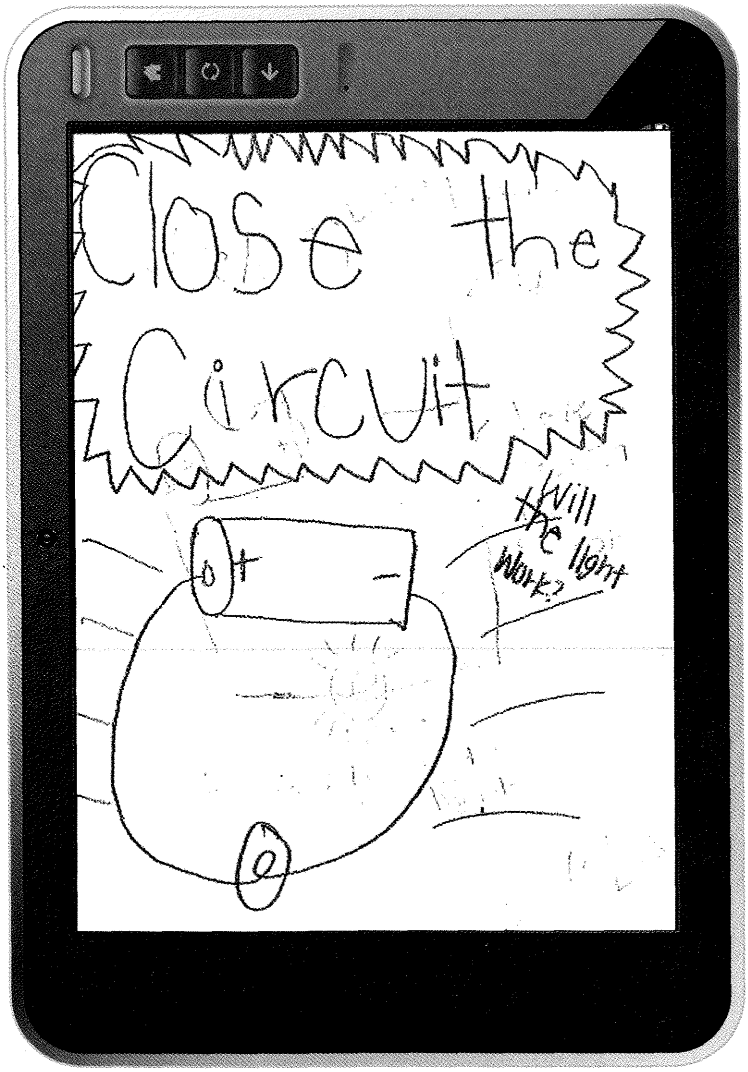


Figure 2. Example of embedded graphics on the homepage.

a joystick to indicate gaming options, on the homepages of their apps. Of these groups, four added graphical encoding to their app's title, and one modeled their app on an existing app. Figure 2 provides an example of homepage graphics.

When discussing their apps, students in one group said, "The first page is a title with a switch flipping on and off making the light bulb flashing." Another group stated, "It shows … probably just gonna show a battery and a few wires lying around and a lightbulb … electricity flow." In this manner, the students put a great deal of emphasis on making the front page of the app graphically intuitive through familiar illustrations.

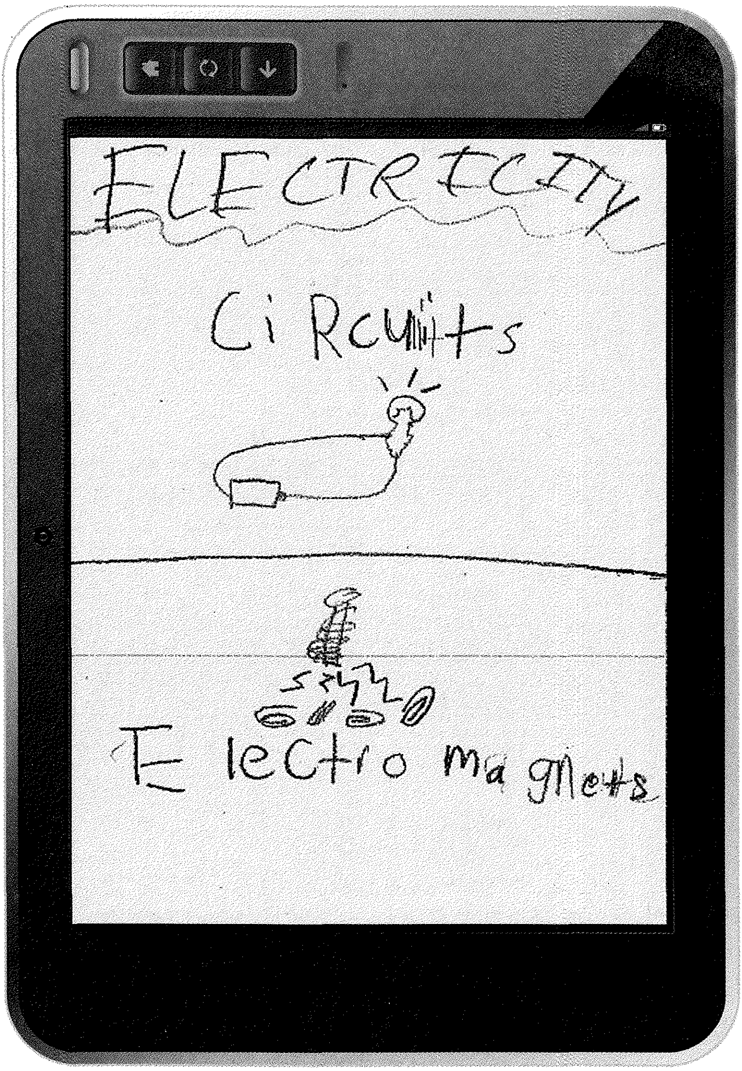


Figure 3. Example of homepage gaming content.

Content of homepage revealed game and other engagement choices. Another important component of the homepages was the presentation of content options related to electricity and circuits. Whereas the groups displayed variability in the specific content presented, they generally considered the homepage as an entry to a game or a way for providing options for choice in exploration. For example, seven of the groups' homepages directly highlighted the gaming features of their apps, including game objectives and directions, options for increasing game difficulty, and challenges related to building simple, parallel, and series circuits. Figure 3 provides an example of a homepage as the entry to a game about circuits and electricity. Other less

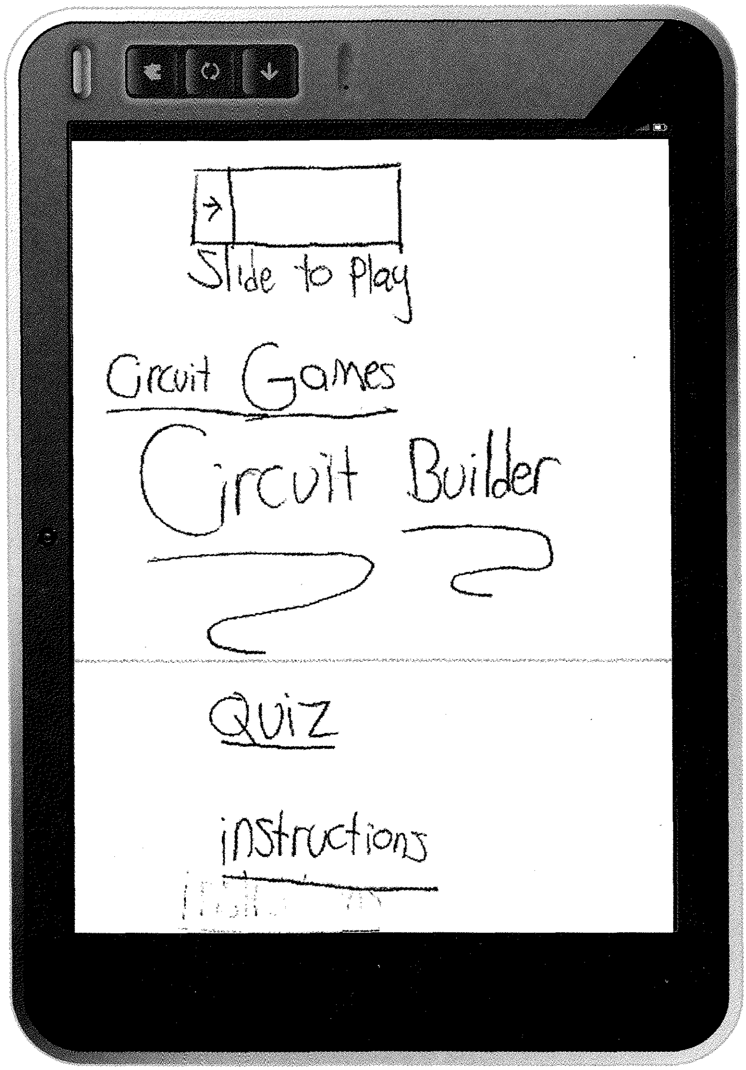


Figure 4. Example of homepage navigations: Slide to Play and underlined links.

common homepage content among the 15 groups included various combinations of navigational links to access further electricity content (n = 3), quiz and trivia options (n = 3), error feedback (n = 2), explicit game objective (n = 2), vocabulary supports (n = 2), options for practice (n = 1), general science content (n = 1), cross content (n = 1), electromagnets (n = 1), and a focused challenge question (n = 1).

The groups spent considerable time discussing the purposes of the homepage in "hooking" students into the content. A student in one group explained, "There is a video clip on the homepage.... We have a 'how to play'.... The how to play option on the homepage kind of teaches you how to play and what

Table 2. Relationship between Students' App Designs and Game Design Elements

Group Design Theme	Game Design Element	Group Frequency & Percentages
Written instructions for gameplay	Game structure (e.g., rules, scoring, navigation) and gameplay mechanics	80% (12/15)
Iconic or illustrated representation of content	Interface	80% (12/15)
Ability to personalize (e.g., text language, background music, gender of avatar, screen colors)	Interface	80% (12/15)
Increased complexity as user progresses	Levels, Adaptive game artificial intelligence (AI)	80% (12/15)
Increased support as user progresses	AI	80% (12/15)
Video instruction to enhance performance	Interface	67% (10/15)
Assessment within the app	AI, dynamic scripting	47% (7/15)
Multimodal presentation of instructions	Interface & accessibility	7% (1/15)

everything means." Another group explained, "You know, when you go into an app like on your iPod, you have like options of instructions or just play. [Pause] We need like an instruction button, like a main menu. [Pause] We can have different levels, like easy and hard."

Clear navigation. A third subtheme that emerged from the groups' homepage designs was the use of clear navigation. Ten groups included extremely explicit forms of navigation through components, such as text providing instruction, such as "Click Here." One student explained the navigation: "So you press it [navigation box with the name of the app], and then the app shows up right here [the bottom of the screen], and you can press different ones [boxes] to get which one you want. So this [all the selection boxes/navigation bar] will always stay here, and this part right here [bottom of screen] will change." To support navigation within the app, three groups used text links, another group included a search box, five groups provided a link to instructions, and one group provided a virtual guide, "Bacon the Pig," to help the user. Figure 4 provides an example of explicit navigation on the homepage wherein the paper protocol includes a slider with the text "Slide to Play."

General Design Themes

In addition to the unique homepage themes, overall design themes included apps as games, multiple settings for personalization, embedded vocabulary support, scaffolded progression in complexity, immediate feedback, explicit navigation, and built-in support for gaining foundational knowledge.

Apps as games. All groups presented their electricity and circuits app in a game-based format. This was particularly interesting, as the research team did not refer to the app design project as game-oriented. Despite the consensus that the app would be a game, there was variability within groups' game designs. The most common gaming elements included gameplay instructions, use of visuals, and options for choice. Table 2 provides

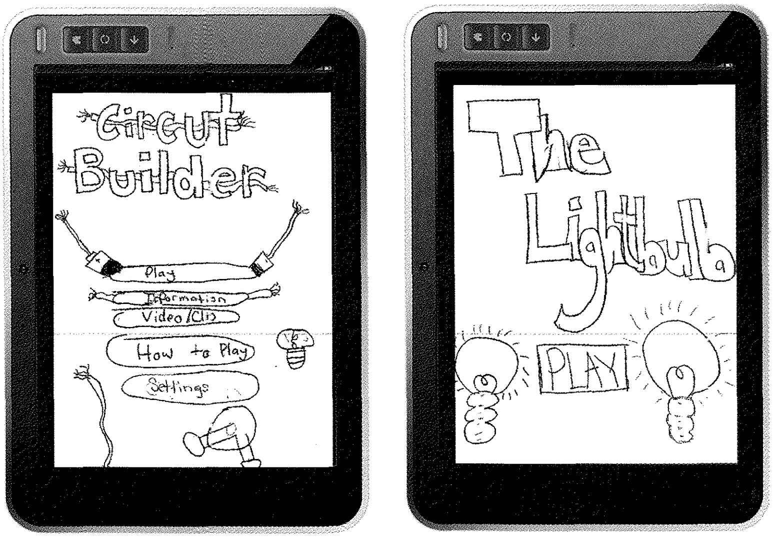


Figure 5. Examples of the app as a game.

frequencies of gaming elements within the students' app designs, and Figure 5 provides two examples of students' conceptualization of the app as a game.

Students discussed how to make this educational app a game. For example, a student in one group stated, "This app is supposed to help people understand circuits and electricity, like how to build a circuit and things about it.... It's more like hands on, you are going to learn from experience [pause]. It's a game." Another group explained that their app is "like a game, and you could have different pieces, and maybe make a parallel or a series circuit, so then it could be fun and you could learn something."

Multiple settings for choice within the app/game. Within the app designs, the students identified choice as important for usability of their game/app. Similar to their assumption that their app designs should be games, all 15 groups included different options for choice within their app, with many including multiple options for choice. Figure 6 provides an example of how students conceptualized providing options for varying the settings within their app designs.

The students offered multiple means of providing choice. The most common choices that the students conceptualized included selection of difficulty levels within the game ($N = 11$), general personalization ($N = 10$), testing options regarding the design of a circuit within the game/app ($N = 7$), and advanced levels for players to access if they demonstrate proficiency in the "regular" game ($N = 6$). In addition, some groups wanted to be able to personalize game mechanics, such as when and how the student could pause or quit the game. One group wanted the ability to build its own level, and another group called for multiplayer options.

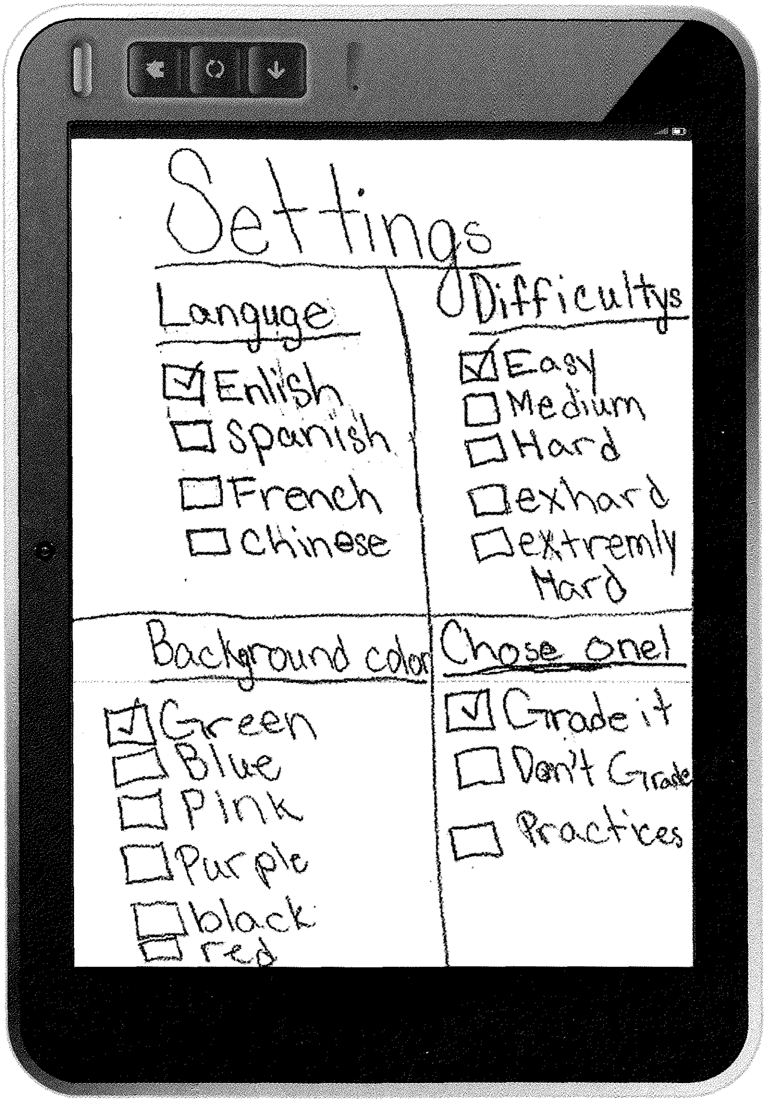


Figure 6. Example of app design choice settings.

The groups had lengthy and varied discussions about what elements to include in their choice settings. One group discussed, "On the settings button, you can select what you want to put in the background … or maybe like language.… you can select a song and have it in the background … you can choose iTunes music from your account." In choosing gameplay level, one group gave total control to the user: "They would be able to switch through the levels and see which one they would like to play.… They would be able to save their game and be able to go to the next level if they were bored with what they were doing right now or if they already knew."

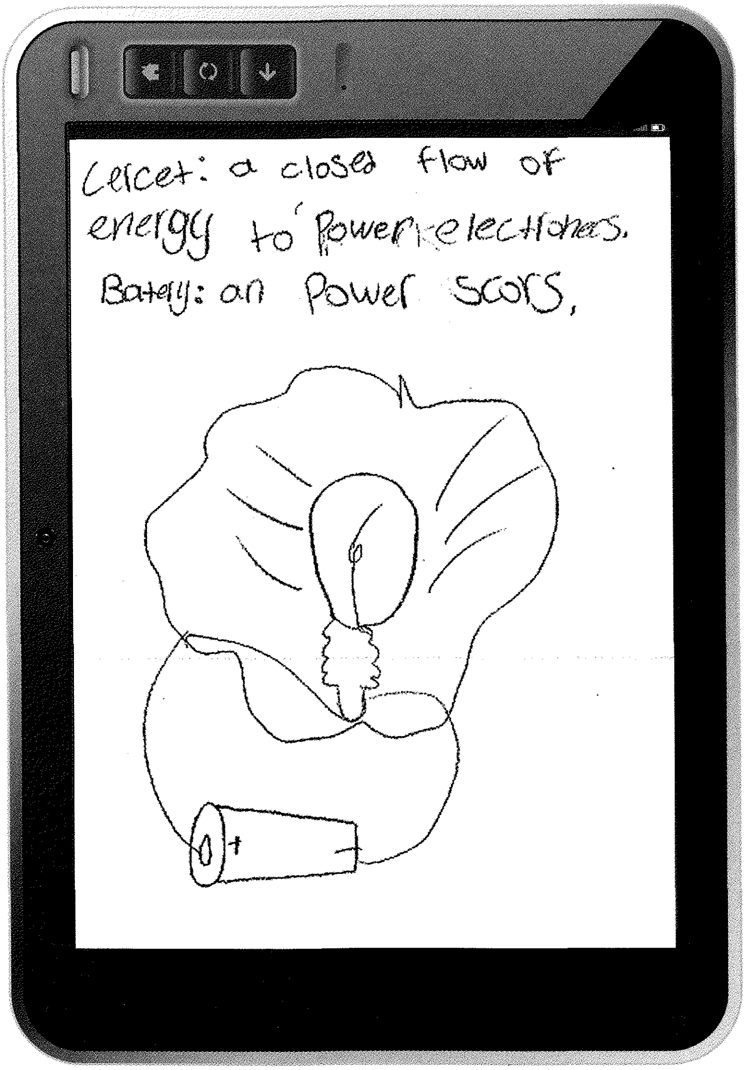


Figure 7. Example of vocabulary supports for the term "Circuit" (spelled as "Cercet").

Embedded vocabulary supports. Although not a majority, five groups included embedded vocabulary support. Of these groups, two added a glossary of terms, two included a visual dictionary, and one provided a key of important terms. Figure 7 (p. 66) provides an example of a visual dictionary option for circuit. The students discussed their ideas about vocabulary: "From the home menu, you would press help, and you would go over to this [vocabulary key]. Then you would click on a component or picture, and it would give you a more precise description." Another group discussed, "We could have a glossary.... It could be, like, lit up, and you could touch it ... and it shows a description." One group thought that the language associated with schematic diagrams might be too difficult for some students at first:

"Not engineer [language], it'll be used the kid way [pause], so it's more kid friendly that way [pause], so it gets harder as the levels move on, and as the levels move on, it can change into engineering [language] but it begins with the first level, and that's why."

Scaffolded progression in complexity. All of the groups incorporated mechanisms in their app designs for building circuits and testing their knowledge of both circuits and electricity. In doing so, 12 groups designed their apps around increasing knowledge and skills related to specific types of circuits (i.e., simple, series, or parallel), and 3 groups designed user options of choosing a preferred circuit. These paper prototypes provided progressions through circuit building with added components such as switches, batteries, and light bulbs. Additionally, two groups also provided the user with incorrectly designed circuits for the users to fix. In doing so, the groups conceptualized this "build" or "fix" activity as steadily increasing in complexity and including various options for receiving assistance. Figure 8 (p. 68) provides examples of students' conceptions of scaffolded progression through increasingly complex content.

One group explained their idea of the leveled building option: "We can, like, have different sections, like Section 1 could be for beginners and Section 2 could be more advanced, like using engineer symbols." Students in this group further explained that the user would progress through the app in a manner that would build knowledge: "They would be able to click on 'Go to the next level,' which would be most likely a parallel circuit and be able to try and correct one of those, and, if they already knew that, then they could try and build one."

Students in all the groups discussed at length the process by which students would receive support and assistance within the app, as they all articulated the need to receive help when needed within the app. Specifically, the groups identified the need for assistance both in understanding the directions and understanding the instructional content. One group discussed, "There's gonna be directions on the app, like before you play the game."

Seven groups also discussed what would happen if a student could not pass the level. One group stated, "We could have, like, a little button up at the top that says, 'Help,' and if someone didn't understand it, they could just press the button and it would tell you how to make the circuit and stuff." Other groups offered further suggestions, such as the option to leave and return to levels of play and options for taking a break from gameplay. In creating opportunities for additional support within the app, the students acknowledged the fact that there would be a percentage of students who may struggle with the content, even with the supports that they built into their app designs.

In addition to app supports for struggling learners, 11 groups discussed how to further challenge students who might already know the content presented within the app. As one group explained, "We have like a grade level,

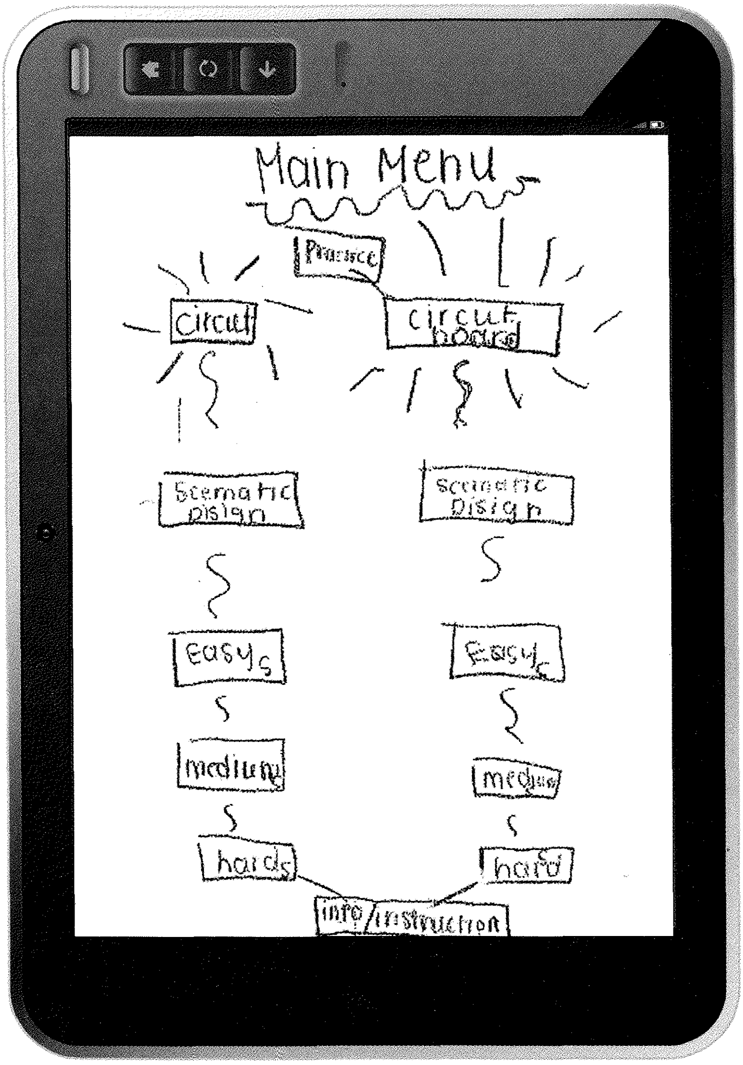


Figure 10. Example of explicit navigation within a homepage main menu.

to provide all the necessary help required. However, they did not want the feedback to interfere with the students' gameplay. One group, for example, advanced the idea of interjecting explicit help and feedback only after a period of struggle to complete the task.

Explicit navigation. The student groups all viewed navigation as both a way of getting through the various aspects of their app and as a means of making the app more engaging and instructional. Similar to the other subthemes, the groups found diverse means of providing explicit navigation. Additionally, all the groups included more than one navigation option (see Figure 10). For example, one group included both a homepage with explicit navigation as well as continuous sidebar navigation throughout the app. Table 3

Table 3. Explicit Navigation Options

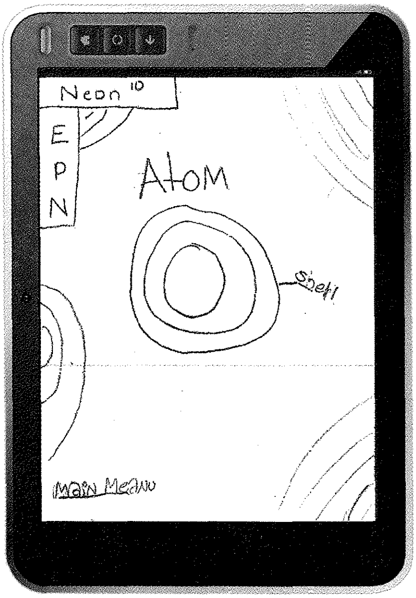
Navigation Options	Group Frequency Percentages
Main menu navigation embedded throughout the app	60% (9/15)
Homepage with main menu navigation options	47% (7/15)
Sidebar navigation	40% (6/15)
Bottom of screen navigation	40% (6/15)
Top of screen navigation	27% (4/15)

provides the types of navigation options that students built into their app paper prototypes.

Groups had many ideas about how students should navigate through the app. One student stated, "At the bottom, we can have like a little button-instructions/info ... and we have like a box that has questions or instructions or help." Another group wanted to have explicit navigation to guide students toward needed content instruction. A student in this group explained, "It'll have a learning info section on the side so you can learn about the settings."

The students also wanted to make sure that their app was engaging and interactive, and they used the navigation within their apps as one means of doing so. They discussed methods of moving circuit parts from one area to another, flipping through content, and overall navigation options that would be fun. One student explained, "We're trying to make it interactive, like you would put your finger on whatever piece of the circuit that you want and drag it to where you want and try to make a complete circuit."

Opportunities to attain foundational content knowledge within the app. In addition to information about circuits, the student groups included options for providing foundational knowledge of electricity within their app designs. This foundational knowledge included content about electromagnets, atoms, lightning, conductors and insulators, safety tips, and definitions of terms for increased understanding of concepts. A student discussing the need for more information to support students who struggle stated, "How about insulators and conductors? You can tell which ones are insulators and which ones are conductors. You could test which one it is in the circuit." Another group of students were concerned about safety and electricity. A student in this group explained, "We are going to have a table of contents that teaches you how to be safe when you are using electricity so you don't hurt yourself." A group that used atoms as part of its main game design recognized that some users might not have the requisite knowledge of atoms to effectively play their game. This group discussed the challenge within their game: "This [E, P, N] stands for electrons, protons, and neutrons, and you have to place them inside the atom, correctly; this is our example, neon." Figure 11 (p. 72) provides two examples of students' conceptions of building foundational knowledge of electricity and circuits.



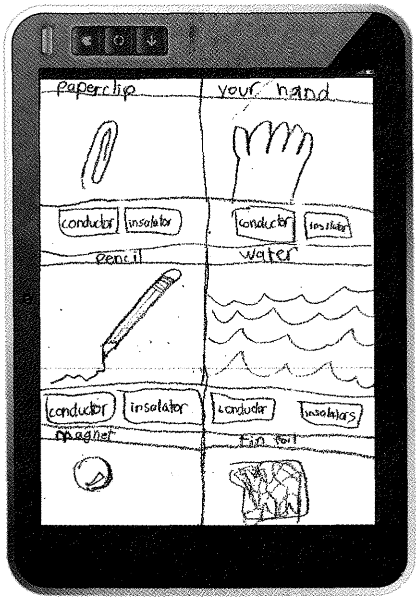


Figure 11. Example of supporting foundational knowledge.

Discussion

This study sought to answer three research questions (RQ):

1. How do students conceptualize a mobile device app that is designed to teach STEM content related to electricity and circuits?
2. What design features are students including in their designs of educational apps?
3. At what level do students include video game design elements in their mobile application prototypes?

In asking these questions, we engaged with the students in a participatory design process to begin to design mobile learning applications that would be relevant to the students. As evidenced by the students' paper prototype designs, they had definite ideas about how to design apps that would support their learning.

RQ1: Conceptualization of a Mobile STEM Teaching App

This study revealed interesting findings about how students conceptualized learning through apps and mobile learning. First, the students conceptualized these apps as games. Second, they recognized that scaffolds should be built into the gameplay to encourage both content mastery and advancement in the game.

Apps as games. When students were given the opportunity to design mobile apps to support learning, they overwhelmingly chose to design game-based activities that included opportunities for choice in how to

"progress" through levels of content knowledge. The students designed their paper prototypes as if the task had been to design a game, although neither the research team nor the classroom instructor advanced this conceptualization. In the recordings of the students' conversations, the students stated numerous times that they favored learning through gameplay.

Interestingly, these app designs incorporated many foundational principles of video game design that have been articulated across an emerging body of research (Gee, 2007; Shute, Ventura, Bauer, & Zapata-Rivera, 2009; VanEck, 2007; Williams, Ma, Feist, Richard, & Prejean, 2007; Yannakakis & Hallam, 2009). The students' designs reflected the process of "gamification," defined by Deterding, Khaled, Nacke, and Dixon (2011) in a working definition as "the use of game design elements in non-game contexts (p. 1)." Key gaming components that are often gamified include point systems and other rewards, leader boards, levels, and epic meanings (Liu, Alexandrova, & Nakajima, 2011).

The fact that all of the groups designed their apps as games lends support to future possibilities of gamifying many aspects of daily life. Gamifying K–12 education can engage and motivate learners within the gaming environment (Lee & Hammer, 2011). Games offer the ability to motivate learners, engage them in authentic content in a virtual manner, and maintain their engagement even in the face of obstacles and challenges. The fact that every group of students designed their apps in a game-based format supports the idea that gamification is an important consideration in the design of instructional technologies to engage and motivate diverse student learners.

Embed supports that enhance student learning. Students' lengthy discussions of how to incorporate scaffolds to support students who may not understand the instructional concepts within the app points to one of the most intriguing findings from this study. For most groups, incorporating leveled play to challenge students was a critical feature of a well-designed educational app to keep their peers engaged and enable them to learn. A majority of groups incorporated a help button that would provide assistance with defining terms, show an informational video, or provide a video demonstration. Other groups offered explicit assistance through simply telling the students what s/he did wrong. These scaffolded supports are consistent with prior research into what assistance students require and when they require it to maintain the user in a state of flow within his/her zone of proximal development (Luckin, 2001; McNamara, Jackson, & Graesser, 2009; Thomas & Young, 2009; VanEck, 2007).

RQ2: Translating Content Knowledge into App Design Features

After completing the EiE curriculum on circuits and electricity, the students were charged with translating that content knowledge into app

designs to educate other students about electricity. In doing so, they took the content and developed games around the concepts of series circuits, circuit components, and schematic diagrams. All of the groups had unique and creative ways in which to present their information within their app. Although many groups decided to design a "build-a-circuit" game, there were variations on this theme across groups. Some groups chose to include a more challenging parallel circuit and vary the number and diversity of components in the circuit.

All students incorporated options for building and testing circuits. These options included repeated practice opportunities and progressions through levels of increasing complexity. This approach is consistent with empirical evidence across a diverse range of technology-enhanced science curricular materials (Marino, 2010). Students also identified pop-up windows as design features that provide immediate feedback and progress monitoring. McNamara and Shapiro (2005) pointed out that metacognitive prompts similar to those described by students in this study could help students develop a deep conceptual understanding of complex phenomena. Another design feature included the use of iconic or illustrative representations of the concepts and vocabulary. Student groups consistently identified these design features in both the landing page and game interface of the mobile apps. These types of representations can be especially beneficial to students with reading difficulties and English language learners who often come to the classroom with deficits in background knowledge and reading abilities (Marino, 2009).

A predominant number of student groups identified the ability to personalize the app as a key design feature. This included options to choose the color scheme, gender of the avatar, and music type and volume level. Dietrel (2009) noted that this high level of autonomy allows students to address, at least in part, their cultural norms. This provides students with increased abilities to relate to the characters in the app or game and leads to enhanced engagement in the learning process. A final design consideration was the use of instruction through an on-screen agent or video to provide explicit instruction about how to successfully use the app. Moreno (2004) and Moreno and Mayer (2005) in concurrent efficacy studies examining this type of feedback concluded that students who were presented with corrective explanations when they made incorrect choices were able to transfer knowledge to different contexts better than students who did not receive the feedback.

RQ3: Video Game Design Elements

There was a clear connection between students' app designs and video game design elements, as illustrated in Table 3 (p. 71). The students' designs focused on allowing the users to continuously attempt to succeed, while offering assistance if needed and/or allowing the users to

continue struggling through while learning and challenging themselves. One student summed it up: "That's why we have the design process, so if we mess up, we can go back and try to make it better." While students' app conceptualization (RQ1) and design characteristics (RQ2) were consistent with findings in the empirical literature, their discussion of the game elements illustrates a nascent perspective on the design process. For example, many of the student designs included a check box (see Figure 5, p. 64) where students would select the level of expertise they have in the content area. Although some students might be able to accurately make this assessment, alternative approaches may be more appropriate. For example, many present-day real-time strategy (RTS) video games include some level of game artificial intelligence (AI). Game AI is the decision making process of the computer-controlled opponents. Although a full discussion of AI is beyond the scope of this manuscript, it should be noted that algorithms similar to those found in RTS games (e.g., Automatic Knowledge Acquisition for Dynamic Scripting; Ponsen, Munoz-Avila, Spronck, & Aha, 2005) offer the potential to inform and improve the educational app and game markets by strategically mapping gameplay difficulty to students' zone of proximal development. Although still emerging, the students did incorporate aspects of game design that are consistent with the theory of maintaining users in a state of flow to increase motivation and engagement with content (Csíkszentmihályi, 1990).

Another game design element that students identified in their apps was the ability to include multiple players. This is consistent with research on social learning in game contexts, which has been shown to help students contextualize learning and maximize intrinsic motivation (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). Other studies (e.g., Ketelhut, 2007; Steinkuehler & Duncan, 2008) support this notion. Several student groups also expressed interest in having the ability to create new levels within the app. This requires strategic consideration by app and game developers at the outset of the design process. Most commercial contemporary educational games (e.g., Filamentgames.com) are guided by a game design document. Once the document is finalized and production begins, it is extremely difficult to integrate functionality that allows users to create their own levels. App and game developers should take this finding into consideration as they develop new products. Teachers and parents can consider open source game development software based on their abilities and learning needs.

Finally, seven student groups identified their progress through the app levels as a form of assessment. This seems especially salient in a period of high-stakes tests that are based on students' mastery of reading and writing. Consider the difficulty that a middle school student who is reading in a second language or at the fourth grade level would have with terms such as generator, alternating currents, prototyping, and perspective. The act of

decoding these words and contextualizing them in meaningful ways may cause cognitive overload. Apps and games can be designed so that game levels are strategically mapped to the same benchmarks as standardized tests (Marino & Beecher, 2010). This approach may be a more accurate indication of what students who struggle with reading actually know about STEM content.

Limitations and Implications for Future Research

We conducted this study with a limited number of fifth grade participants in one setting. Therefore, the results may not be generalizable to other contexts. Additional studies should examine different grade levels and content areas to determine if these results are replicable in other settings. We are currently conducting research with middle school students in this area. Preliminary evidence suggests that as students mature, their desire to have control over increasingly sophisticated aspects of the game, such as the narrative from the game design document, increases.

The students in this study were grouped into heterogeneous groups. Consequently, the data provided information only about the ideas of the groups rather than about individual students. We know that students bring their own experiences, interpretation of content, and preferences into their design decisions (see Figure 1, p. 56), but no studies have yet investigated how these individual characteristics inform children's design decisions. It would be useful to consider the differences of preferences among individual students as well as homogeneous groups of students to learn how individual students characteristics inform their design decisions as well as whether students who struggle and those who are English language learners would have different preferences than their peers. Additionally, although efforts were made to avoid interactions between the groups during data collection, there was no guarantee that the participants did not discuss their app designs outside of class time. Future studies should consider conducting these types of studies in different locations to avoid possible intergroup discussions.

Lastly, there is a great deal of conversation about effective K–12 engineering education pedagogy and how students should be introduced to the engineering design process. It was evident from this study that students enjoyed the process of designing an app based on their knowledge of electricity and circuits. However, this study presented a one-shot data collection process that did not allow students to fully go through a design process. A logical extension of this study would be to integrate it into engineering design instruction and allow students to go through a more prolonged design process experience as a way of identifying a problem or area of need, planning for the design of the app, designing the paper prototypes, critiquing their own and others' designs, and then redesigning their apps. In this manner, students could learn about game design principles while engaging in participatory app design through an authentic engineering process.

Implications for Instructional Designers

Fei-Chen, Tsai, Finger, Chen, and Dowming (2008) concluded that the quality of technology-based learning environments is critical for student satisfaction. This study revealed that fifth grade students had strong conceptions of how mobile technology applications can support their learning and the learning of their peers. The students identified salient features (see Table 3, p. 71) that should be considered when designing educational technologies. Additionally, because the students identified features that are often common in commercial games, designers working on educational technologies should integrate those features of commercial games that children find useful and motivating, including the gamification of learning, multiple options for customizing the learning/gaming environment, and scaffolded progressions in difficulty. Lastly, this study provided front-end information from children about the design of a mobile learning application. It would be important to include students' feedback and insights throughout the technology development process. Finally, the use of apps or games as assessments can occur only when the back end of the technology gathers user analytics and presents it to teachers and parents in meaningful ways.

Conclusion

There is still a great deal to learn about how students can inform the design process of educational technologies. This study revealed that fifth graders can participate in the design process as collaborators. It also highlighted the expectations that these students have about the gamification of learning. Gaming and learning with technology will continue to augment traditional learning environments for the foreseeable future. Educators, technology developers, and researchers should consider where and when gaming elements can be used to support, enhance, and supplement learning.

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